SHRINKAGE OF WOOD IN SHIP CONSTRUCTION

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SHRINKAGE OF WOOD IN SHIP CONSTRUCTION

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Wood, like many other materials, shrinks as it loses moisture and swells as it absorbs moisture.

While green, freshly cut logs may contain water ranging in quantity from 30 to 300 percent, based on the weight of the oven-dry wood, the removal of only the last 25 or 30 percent of this moisture content has the effect of shrinking the wood upon drying; and since wood in service is never totally dry, the possible shrinkage effect falls within a relatively narrow range of moisture content.

Water is held in the wood in two distinct ways -- as imbibed water in the walls of the wood cells, and as free water in the cell cavities. When wood begins to dry, the free water leaves first, followed by the imbibed water. The fiber-saturation point is the stage in the drying or wetting of wood at which the cell walls are saturated and the cell cavities are free from water. For most woods, this point is between 25 and 30 percent moisture content.

The dimensions of wood change only when the moisture content drops below the fiber-saturation point. Since in seasoning green wood, the surface dries more rapidly than the interior and reaches the fiber-saturation point first, shrinkage may start near the surface of a piece while the average moisture content of the board or timber is still considerably above the fiber-saturation point. Wood shrinks most in the direction of the annual growth rings (tangentially), about one-half to two-thirds as much across these rings (radially), and very little, as a rule, along the grain (longitudinally). The combined effects of radial and tangential shrinkage on the shape of various sections in drying from the green condition are illustrated in figure 1. When a board or portion of a board is cross-grained, the lengthwise shrinkage resulting from a combination of crosswise and longitudinal shrinkage is greater than that in a straight-grained piece. Shrinkage is usually expressed as a percentage of the green dimensions, which represent the natural size of the piece. Table 1 gives the range in shrinkage in different directions for most of the commercially important native species.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Shrinkage in drying is proportional to the moisture lost below the fiber-saturation point. Approximately one-quarter of the total shrinkage possible has occurred in wood seasoned to a moisture content of 18 to 20 percent, about one-half when the moisture content is 12 to 13 percent, and about three-fourths in lumber kiln dried to a moisture content of about 6 to 7 percent. Wood is a hygroscopic substance; that is, it has the property of absorbing or giving off moisture according to the conditions of the surrounding atmosphere. When wood is subjected to a constant temperature and relative humidity, it will in time come to a definite moisture content determined by the prevailing humidity, which is called the equilibrium moisture content. This relationship between the moisture content of wood and the surrounding atmospheric conditions is shown on figure 2. Atmospheric temperatures are constantly changing, both during a single day and with the seasons. The relative humidity also fluctuates. The rate of exchange of moisture between wood and atmosphere is, however, comparatively slow, and the equilibrium moisture content is based on the average humidity prevailing over an extended period rather than on changes during very short periods, even though fluctuations may then be through a wide range. Thickness of the wood is also a factor, the moisture content of thin material reacting to atmospheric changes more rapidly than thick material.

Surface coatings retard the rate of exchange of moisture between the wood and the atmosphere. All wood used in ships above the water line, as well as interior parts not exposed to water, will in time attain a moisture content in equilibrium with the atmospheric conditions surrounding it. This moisture content may vary more or less according to changes in atmospheric conditions and exposure to wetting, but will in general remain consistently below the fiber-saturation point. Exterior planking below the water line that is exposed to the vessel's interior atmosphere will have a moisture content on the inner face that is below the fiber-saturation point, while its outer face when in contact with the water will be at or above the fiber-saturation point. Deck boats and other types of small water craft that are kept out of the water most of the time will attain a moisture content consistently below the fiber-saturation point, probably as low as 10 percent at times.

Hence, if wood intended for use in boats is adequately seasoned and installed at a moisture content in accord with its service conditions, there is every prospect of satisfactory performance without serious changes in size or distortion of section. On the other hand, if green or partially seasoned material is used under conditions such that further drying will take place after installation, some shrinkage may be expected.

In general, the heavier species of wood shrink more across the grain than the lighter ones. Heavier wood of the same species also shrinks in this direction more than lighter wood. When freedom from shrinkage is a more important requirement than hardness or strength, as, for example, in the planking of small boats, a lightweight species should be chosen. When it is important to combine hardness or strength with low shrinkage, such as in the case of treenails, some species like black locust is to be preferred. Average tangential, radial, and volumetric shrinkages for individual

domestic species when dried from the green condition to various moisture-content values are given in table 2. The average tangential, radial, and volumetric shrinkage for a limited number of tropical species when dried from the green to an oven-dry condition is given in table 3.

Theoretically, and for practical purposes, the normal moisture content-shrinkage relation may be considered a direct one, from zero shrinkage at the fiber-saturation point to maximum shrinkage at zero moisture content. Actually, however, the relationship is similar in boards to the curves in figure 3. The curves represent average values, and the shrinkage of an individual board may, of course, be above or below the average amount indicated.

Changes in moisture content in seasoned wood, such as those caused by seasonal variations in relative humidity, produce changes in dimension that are proportional to the moisture-content changes. For example, assume that a piece of flat-sawed southern yellow pine sheathing at 12 percent moisture content loses 5 percent of its moisture. The shrinkage curve (marked "tangential") indicates that the shrinkage in width from the green condition to 7 percent moisture content would be 5 percent, and that from the green condition to 12 percent moisture content would be 3-1/2 percent. The difference of 1-1/2 percent is the shrinkage in the width of the board due to the 5-percent loss in moisture. These curves represent average values, and the shrinkage of an individual board may be somewhat below or above the indicated amount.

Moisture pickup below the fiber-saturation point causes expansion or swelling just as moisture loss causes shrinkage. For instance, reversing the above example, a pickup of 5 percent in moisture content from 7 to 12 percent would cause a flat-sawed board to swell about 1-1/2 percent of the green width.

Where swelling is restrained during a cycle of moisture pickup, such as in the case of tightly fitted planking or decking, the surfaces tend to buckle or become deformed or slightly crushed at the edges. Upon redrying to the original moisture content, such pieces will shrink and assume a dimension somewhat less than before swelling started, and the joint will open. Repeated cycles of swelling and shrinking under pressure in the course of time cause the piece to become narrower. Tight recaulking when the joints are opened by shrinkage will cause more rapid loss of dimension than would occur if the caulking is tapped in lightly. Moreover, seam composition should be of a type that will remain soft in service so that it can expand and contract as the wood shrinks and swells. Since the swelling and shrinkage are proportional to the width of the piece, it follows that the narrower the piece is the less the joint will open or close. With proper caulking, the joint can take up some of the expansion before the forces developed tend to deform the contact surfaces of the wood; hence, on the basis of shrinkage effects, narrow material gives better service than wide material.

Exposed decking, particularly if unpainted, is subject to very severe exposure and rapid moisture changes, hence, the width used is generally

not more than one-third greater than the thickness, and often less. Planking contributes materially to the strength of the vessel and, within certain limits, the wider the plank is the greater are its strength properties. On the other hand, to prevent trouble from expansion, particularly above the water line, the width must be limited. Since the exposure is less severe than for decking and the material is invariably well protected with paint to minimize moisture changes, such planking can safely be wider than decking, and generally, the width is equal to three or four times its thickness.

Lifeboats, deck boats, utility boats, or similar types that are out of the water the greater part of the time should be constructed of material having a moisture content that is at or slightly below that which they will attain in service. This means a moisture content generally not less than 10 percent and not more than 18 percent. To prevent rapid moisture changes, such boats should be well painted, inside and out. Any further protection from sun and rain, such as boat covers, will minimize moisture changes and lengthen the useful life of the boat. When not in service, such boats should be supported at least a foot above the ground and should preferably be stored in open, well ventilated, unheated sheds, or covered to protect them from the sun.

Effects of Change of Moisture Content on Bent Wood Members

The checks that develop in bent members, such as ribs, frames, and similar parts, are largely the result of unequal drying but the stresses set up because of the bending accentuate the checks to some degree. Heat in combination with moisture tends to plasticize wood, hence, stock intended for bending is heated with hot water or steam immediately before bending. The contained heat causes rapid evaporation from the surface, thus setting up the first factor favorable for checking. As the drying progresses after the stock has cooled, any checks present may be extended. Checking may be minimized by using stock having a moisture content of 15 to 20 percent. If the moisture content is 12 percent or less, the breakage during bending is likely to be more frequent than if more moisture were present.

Some change of shape of bent members that are not restrained may be expected with a change of moisture content. Whether restrained or not, such parts develop complex interior stresses because of moisture changes and resulting shrinkage. For example, assume the frame to be semicircular. When loss of moisture occurs the radial dimension, being across the grain, tends to decrease, which in turn leads to decreases in the length of the inner or outer arc, or both. The upset fibers in the inner arc also tend to shrink while there is little or no tendency for the fibers in the outer arc to shrink. Consequently, if the piece is not restrained the curvature tends to increase or "close the bend" (fig. 4). If it is restrained so that no change in curvature can take place, a tension stress is developed across the grain (radially) with compression stress in the outer arc and tension stress in the inner arc.

Conversely, an increase in moisture content results in radial swelling and swelling of the upset fibers of the inner arc, tending to "open" or decrease the curvature. If the piece is restrained from movement, the stresses developed are the reverse of those caused by shrinkage.

Breakage of bent members after the bending operation -- often after they have been installed in the boat -- is in some cases caused by shrinkage stresses or a combination of such stresses with some weakness in the piece, such as localized diagonal grain, a concealed defect, check or split, or a partial undetected break that occurred in bending.

Shrinkage of Plywood

Normal straight-grained wood has relatively high strength and slight shrinkage properties in the direction of the grain. Across the grain, however, the shrinkage is relatively high and the strength property is low. In plywood with the grain of adjacent plies perpendicular, the lateral shrinkage of adjacent plies is almost completely restrained, and the length and width of plywood panels are hence only slightly affected by moisture content changes. The shrinkage in the thickness of the plies, however, is unopposed, hence the panel will shrink in thickness just as does normal wood.

The shrinkage of a plywood panel in the two lateral directions will be the sum of the longitudinal shrinkage and the longitudinal compression assumed by the plies. This shrinkage will vary with the species, the ratio of ply thicknesses, the number of plies, the character of the grain, and the combination of species. The average shrinkage obtained from several hundred tests on a variety of combinations of species and thicknesses in bringing 3-ply wood from the soaked to the oven-dry condition was about 0.45 percent parallel to the face grain and 0.67 percent perpendicular to the face grain. The species included in the tests were basswood, birch, black walnut, chestnut, elm, mahogany, Spanish cedar, spruce, sugar maple, sweetgum, tupelo, and yellowpoplar.

From this it is seen that the shrinkage of plywood is only about one-tenth as great as that across the grain of an ordinary board. The total lateral shrinkage of a 1-1/2-inch southern yellow pine board with two 1/12-inch sweetgum face veneers was only 1 percent, or about one-seventh of the normal shrinkage. The values given for shrinkage are based on a moisture content ranging from a green or soaked condition to an oven-dry condition. In service the change in moisture content will be much less, generally not more than enough to cause a dimensional change of one-fourth to one-half of that represented in the tests.

Table 1.--Range in average shrinkage of a number of native species of wood

Direction of shrinkage	From green to oven-dry condition	From green to air-dry condition (12 to 13 percent moisture content)
	Percent of green size	Percent of green size
Tangential	4.3 to 14	2.1 to 7
Radial	2 to 8.5	1 to 4.2
Longitudinal	.1 to .2	.05 to .1
Volumetric	7 to 21	3.5 to 10.5

Table 2.--Shrinkage values for commercially important woods grown in the United States

Species	Shrinkage (percent of dimension when green) from green to --											
	18 or 20 percent moisture[1] (estimated values)			12 or 13 percent moisture[2] (estimated values)			6 or 7 percent moisture[3] (estimated values)			Oven dried to 0 percent moisture (test values)		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Ash:												
Black	1.2	2.0	3.8	2.5	3.9	7.6	3.8	5.8	11.4	5.0	7.8	15.2
Commercial white[4]	1.2	1.9	3.2	2.3	3.8	6.4	3.4	5.6	9.6	4.6	7.5	12.8
Oregon	1.0	2.0	3.3	2.0	4.0	6.6	3.1	6.1	9.9	4.1	8.1	13.2
Basswood	1.6	2.3	4.0	3.3	4.6	7.9	5.0	7.0	11.8	6.6	9.3	15.8
Beech, American	1.3	2.8	4.1	2.6	5.5	8.2	3.8	8.2	12.2	5.1	11.0	16.3
Birch[5]	1.7	2.2	4.1	3.4	4.4	8.2	5.2	6.7	12.2	6.9	8.9	16.3
Birch, paper	1.6	2.2	4.0	3.2	4.3	8.1	4.7	6.4	12.2	6.3	8.6	16.2
Butternut	.8	1.5	2.6	1.6	3.0	5.1	2.5	4.6	7.6	3.3	6.1	10.2
Cedar:												
Alaska yellow-	.7	1.5	2.3	1.4	3.0	4.6	2.1	4.5	6.9	2.8	6.0	9.2
Eastern red	.8	1.2	2.0	1.6	2.4	3.9	2.3	3.5	5.8	3.1	4.7	7.8
Incense	.8	1.3	1.9	1.6	2.6	3.8	2.5	3.9	5.7	3.3	5.2	7.6
Northern white-	.5	1.2	1.8	1.0	2.4	3.5	1.6	3.5	5.2	2.1	4.7	7.0
Port Orford white-	1.2	1.7	2.5	2.3	3.4	5.0	3.4	5.2	7.6	4.6	6.9	10.1
Atlantic white-	.7	1.3	2.1	1.4	2.6	4.2	2.1	3.9	6.3	2.8	5.2	8.4
Western red-	.6	1.2	1.9	1.2	2.5	3.8	1.8	3.8	5.8	2.4	5.0	7.7
Cherry, black	.0	1.8	2.9	1.8	3.6	5.8	2.8	5.3	8.6	3.7	7.1	11.5
Chestnut	.8	1.7	2.9	1.7	3.4	5.8	2.6	5.0	8.7	3.4	6.7	11.6
Cottonwood:												
Eastern	1.0	2.3	3.5	2.0	4.6	7.0	2.9	6.9	10.6	3.9	9.2	14.1
Northern black	.9	2.2	3.1	1.8	4.3	6.2	2.7	6.4	9.3	3.6	8.6	12.4
Cypress, southern	1.0	1.6	2.6	1.9	3.1	5.2	2.8	4.6	7.9	3.8	6.2	10.5
Douglas-fir:												
Coast region	1.2	2.0	3.0	2.5	3.9	5.9	3.8	5.8	8.8	5.0	7.8	11.8
"Inland Empire" region	1.0	1.9	2.7	2.0	3.8	5.4	3.1	5.7	8.2	4.1	7.6	10.9
Rocky Mountain region	.9	1.6	2.6	1.8	3.1	5.3	2.7	4.6	8.0	3.6	6.2	10.6
Elm:												
American	1.0	2.4	3.6	2.1	4.8	7.3	3.2	7.1	11.0	4.2	9.5	14.6
Rock	1.2	2.0	3.5	2.4	4.0	7.0	3.6	6.1	10.6	4.8	8.1	14.1
Slippery	1.2	2.2	3.4	2.4	4.4	6.9	3.7	6.7	10.4	4.9	8.9	13.8
Fir:												
Balsam	.7	1.6	2.7	1.4	3.3	5.4	2.1	5.0	8.1	2.8	6.6	10.8
Commercial white[6]	.8	1.8	2.4	1.6	3.6	4.9	2.4	5.3	7.4	3.2	7.1	9.8
Noble	1.1	2.1	3.1	2.2	4.1	6.2	3.4	6.2	9.4	4.5	8.3	12.5
Gum:												
Black	1.1	1.9	3.5	2.2	3.8	7.0	3.3	5.8	10.4	4.4	7.7	13.9
Sweet-	1.3	2.5	3.8	2.6	5.0	7.5	3.9	7.4	11.2	5.2	9.9	15.0
Tupelo	1.0	1.9	3.1	2.1	3.8	6.2	3.2	5.7	9.4	4.2	7.6	12.5
Hackberry	1.2	2.2	3.4	2.4	4.4	6.9	3.6	6.7	10.4	4.8	8.9	13.8
Hemlock:												
Eastern	.8	1.7	2.4	1.5	3.4	4.8	2.2	5.1	7.3	3.0	6.8	9.7
Western	1.1	2.0	3.0	2.2	4.0	6.0	3.2	5.9	8.9	4.3	7.9	11.9
Hickory:												
Pecan[7]	1.2	2.2	3.4	2.4	4.4	6.8	3.7	6.7	10.2	4.9	8.9	13.6
True[8]	1.8	2.8	4.5	3.6	5.7	9.0	5.5	8.6	13.4	7.3	11.4	17.9
Honey locust	1.0	1.6	2.7	2.1	3.3	5.4	3.2	5.0	8.1	4.2	6.6	10.8
Larch, western	1.0	2.0	3.3	2.1	4.0	6.6	3.2	6.1	9.9	4.2	8.1	13.2
Locust, black	1.1	1.7	2.4	2.2	3.4	4.9	3.3	5.2	7.4	4.4	6.9	9.8
Magnolia:												
Cucumbertree	1.3	2.2	3.4	2.6	4.4	6.8	3.9	6.6	10.2	5.2	8.8	13.6
Southern	1.4	1.6	3.1	2.7	3.3	6.2	4.0	5.0	9.2	5.4	6.6	12.3
Mahogany, West Indies	.9	1.2	1.9	1.7	2.4	3.8	2.6	3.6	5.8	3.5	4.8	7.7
Maple:												
Bigleaf	.9	1.8	2.9	1.8	3.6	5.8	2.8	5.3	8.7	3.7	7.1	11.6
Black	1.2	2.3	3.5	2.4	4.6	7.0	3.6	7.0	10.5	4.8	9.3	14.0
Red	1.0	2.0	3.3	2.0	4.1	6.6	3.0	6.2	9.8	4.0	8.2	13.1
Silver	.8	1.8	3.0	1.5	3.6	6.0	2.2	5.4	9.0	3.0	7.2	12.0
Sugar	1.2	2.4	3.7	2.4	4.8	7.4	3.7	7.1	11.2	4.9	9.5	14.9
Oak:												
Red[9]	1.1	2.2	3.7	2.2	4.5	7.4	3.2	6.8	11.1	4.3	9.0	14.8
White[10]	1.4	2.3	4.0	2.7	4.6	8.0	4.0	7.0	12.0	5.4	9.3	16.0
Pine:												
Loblolly	1.2	1.8	3.1	2.4	3.7	6.2	3.6	5.6	9.2	4.8	7.4	12.3
Lodgepole	1.1	1.7	2.9	2.2	3.4	5.8	3.4	5.0	8.6	4.5	6.7	11.5
Longleaf	1.3	1.9	3.0	2.6	3.8	6.1	3.8	5.6	9.2	5.1	7.5	12.2
Eastern white-	.6	1.5	2.0	1.2	3.0	4.1	1.7	4.5	6.2	2.3	6.0	8.2
Red	1.2	1.8	2.9	2.3	3.6	5.8	3.4	5.4	8.6	4.6	7.2	11.5
Ponderosa	1.0	1.6	2.4	2.0	3.2	4.8	2.9	4.7	7.2	3.9	6.3	9.6
Shortleaf	1.1	1.9	3.1	2.2	3.8	6.2	3.3	5.8	9.2	4.4	7.7	12.3
Sugar	.7	1.4	2.0	1.4	2.8	4.0	2.2	4.2	5.9	2.9	5.6	7.9
Western white	1.0	1.8	3.0	2.0	3.7	5.9	3.1	5.6	8.8	4.1	7.4	11.8
Poplar, yellow	1.0	1.8	3.1	2.0	3.6	6.2	3.0	5.3	9.2	4.0	7.1	12.3
Redwood	.6	1.1	1.7	1.3	2.2	3.4	2.0	3.3	5.1	2.6	4.4	6.8
Spruce:												
Eastern[11]	1.1	1.9	3.2	2.2	3.8	6.3	3.2	5.8	9.4	4.3	7.7	12.6
Engelmann	.8	1.6	2.6	1.7	3.3	5.2	2.6	5.0	7.8	3.4	6.6	10.4
Sitka	1.1	1.9	2.9	2.2	3.8	5.8	3.2	5.6	8.6	4.3	7.5	11.5
Sycamore, American	1.3	1.9	3.6	2.6	3.8	7.1	3.8	5.7	10.6	5.1	7.6	14.2
Tamarack	.9	1.8	3.4	1.8	3.7	6.8	2.8	5.6	10.2	3.7	7.4	13.6
Walnut, black	1.3	1.8	2.8	2.6	3.6	5.6	3.9	5.3	8.5	5.2	7.1	11.3

[1] These shrinkage values have been taken as one-fourth the shrinkage to the oven-dry condition as given in the last 3 columns of this table.

[2] These shrinkage values have been taken as one-half the shrinkage to the oven-dry condition as given in the last 3 columns of this table.

[3] These shrinkage values have been taken as three-fourths the shrinkage to the oven-dry condition as given in the last 3 columns of this table.

[4] Average of Biltmore white ash, blue ash, green ash, and white ash.

[5] Average of sweet birch and yellow birch.

[6] Average of lowland white fir and white fir.

[7] Average of bitternut hickory, nutmeg hickory, water hickory, and pecan.

[8] Average of bigleaf shagbark hickory, mockernut hickory, pignut hickory, and shagbark hickory.

[9] Average of black oak, laurel oak, pin oak, red oak, scarlet oak, southern red oak, swamp red oak, water oak, and willow oak.

[10] Average of bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.

[11] Average of black spruce, red spruce, and white spruce.

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Table 3.--Tropical woods -- percent directional and volume shrinkage from green to oven-dry condition

(Excerpt from Tropical Woods, Vol.71,9/1/42, by E.S.Harrar, Duke University)

Species	Radial	Tangential	Volume
Aboudikro (Ivory Coast) Entandrophragma cylindricum	5.63	9.45	15.69
Allacede (Phil. Is.) Wallaceodendron celebicum	4.65	6.97	12.48
Almon (Phil. Is.) Shorea eximia	6.99	7.69	15.54
Amaranth (Trop. Amer.) Peltogyne paniculata	3.78	5.80	10.17
Amarello (Brazil) Plathymenia reticulata	6.07	6.31	12.94
Andiroba (Trop. Amer.) Carapa guianensis	5.44	8.23	14.57
Araca (Brazil) Terminalia aff. januarensis	3.01	4.89	10.64
Avodire (W. Africa) Turraeanthus africana	4.03	6.19	10.64
Ayous (W. Africa) Triplochiton scleroxylon	2.49	5.11	7.84
Blackbean, Australian Castanospermum australe	2.76	7.04	10.07
Bosse (W. Africa) Guarea cedrata	3.50	5.96	9.83
Boxwood, Indian (Buxus sempervirens	5.05	10.76	16.48
Bubinga (W. Africa) Copaifera aff. Tessmanii	4.13	9.56	15.38
Capomo (Trop. Amer.) Brosimum alicastrum	5.12	9.40	15.36
Cherry, W. African Mimusops heckelii	5.30	7.80	13.72
Coccobolo (Cent. Amer.) Dalbergia retusa	2.65	4.26	7.20
Ebony, Macassar (Dutch E. I.) Diospyros macassar	5.20	9.14	14.89
Framerie (W. Africa) Terminalia ivorensis	4.63	6.18	14.18

(Sheet 1 of 4)

Table 3.--Tropical woods -- percent directional and volume shrinkage from green to oven-dry condition (continued)

Species	Radial	Tangential	Volume
Gaboon (W. Africa) *Aucoumea klaineana*	5.63	6.10	12.62
Garapa (Brazil) *Apuleia praecox*	4.53	8.11	13.95
Goncalo alves (Trop. Amer.) *Astronium fraxinifolium*	5.63	8.33	14.70
Greenheart (Br. Guiana) *Ocotea rodiaei*	3.41	4.22	8.00
Guapinol (Trop. Amer.) *Hymenaea courbaril*	3.00	5.22	8.65
Iroko (W. Africa) *Chlorophora excelsa*	3.44	4.77	8.49
Koa (Hawaii) *Acacia koa*	5.47	6.19	12.39
Koko (Andaman Is.) *Albizzia lebbeck*	2.78	6.62	9.74
Lacewood (Australia) *Cardwellia sublimis*	3.79	7.20	11.47
Lauaan, Red (Phil. Is.) *Shorea negrosensis*	3.27	8.04	11.86
Laurel, East Indian *Terminalia tomentosa*	5.87	8.98	15.43
Limba (W. Africa) *Terminalia superba*	5.13	8.06	14.37
Macacauba (Brazil) *Platymiscium polystachyum*	4.63	6.42	11.51
Mahogany, African *Khaya ivorensis*	4.96	8.36	16.88
Mahogany, Columbian *Swietenia macrophylla*	2.46	3.80	6.53
Mahogany, Cuban *Swietenia mahagoni*	2.43	4.47	7.14
Mahogany, St. Jago *Swietenia mahogoni*	3.19	4.13	7.89
Mahogany (Peru) *Swietenia macrophylla*	3.15	4.39	8.07
Mahogany (San Domingo) *Swietenia mahogoni*	2.06	2.91	5.22
Mansonia (W. Africa) *Mansonia altissima*	4.63	6.42	11.51
Maple, Australian *Flindersia brayleyana*	3.74	8.36	15.47

(Sheet 2 of 4)

Table 3.--Tropical woods -- percent directional and volume shrinkage from green to oven-dry condition (continued)

Species	Radial	Tangential	Volume
Movingui (W. Africa) *Distemonanthus benthamianus*	3.08	5.18	10.66
Narra (Phil. Is.) *Pterocarpus indicus*	2.54	3.63	6.81
Orientalwood (Australia) *Endiandra palmerstoni*	4.54	8.55	13.74
Padouk, African *Pterocarpus soyauxii*	3.81	4.41	8.52
Padouk, Andaman *Pterocarpus dalbergioides*	3.50	4.06	7.94
Paldao (Phil. Is.) *Dracontomelum dao*	4.15	8.55	13.31
Palosapis (Phil. Is.) *Anisoptera thurifera*	4.65	7.61	13.37
Pearwood (Europe) *Pyrus communis*	4.30	14.65	19.79
Peroba, White (Brazil) *Paratecoma peroba*	3.41	6.20	9.82
Primavera (Cent. Amer.) *Cybistax donnell-smithii*	4.23	5.05	9.62
Rosewood, Brazilian *Dalbergia nigra*	3.41	7.70	12.31
Rosewood, East Indian *Dalbergia latifolia*	2.10	5.71	7.18
Rosewood, French (Madagascar) *Dalbergia greveana*	3.25	5.38	9.17
Sapele (W. Africa) *Entandrophragma cyclindricum*	5.91	7.42	13.99
Satinwood, Ceylon *Chlorophora swietenia*	5.71	8.51	14.94
Satinwood, W. Indian *Zanthoxylum flavum*	6.12	9.18	15.18
Satiny, Red (Australia) *Syncarpia hillii*	7.06	7.96	16.93
Tabasara (Trop. Amer.) *Prioria copaifera*	2.21	7.31	9.87
Taku (Trop. Amer.) *Diplotropis guianensis*	1.21	2.63	3.86
Tanguile (Phil. Is.) *Shorea polysperma*	4.47	7.84	12.53

(Sheet 3 of 4)

Table 3.--Tropical woods -- percent directional and volume shrinkage from green to oven-dry conditions (continued)

Species	Radial	Tangential	Volume
Teak (Java) Tectona grandis	6.36	9.55	16.34
Tigerwood (W. Africa) Lovoa klaineana	5.32	8.78	13.64
Tulipwood (Brazil) Dalbergia aff. variabilis	4.53	13.03	18.32
Zebrawood (W. Africa) Macrolobium sp.	4.87	10.24	15.90

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[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]
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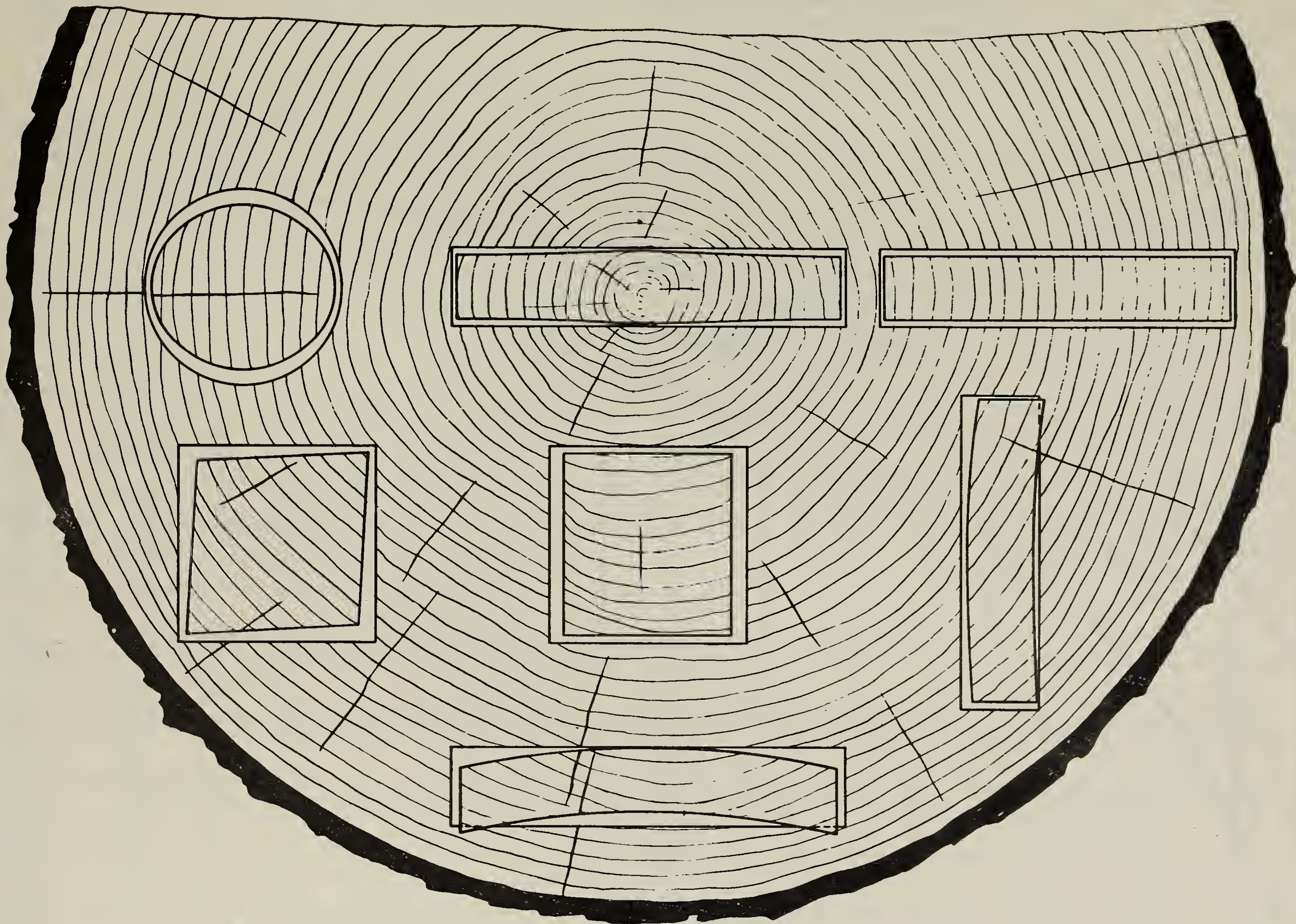

Fig. 1. Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial.

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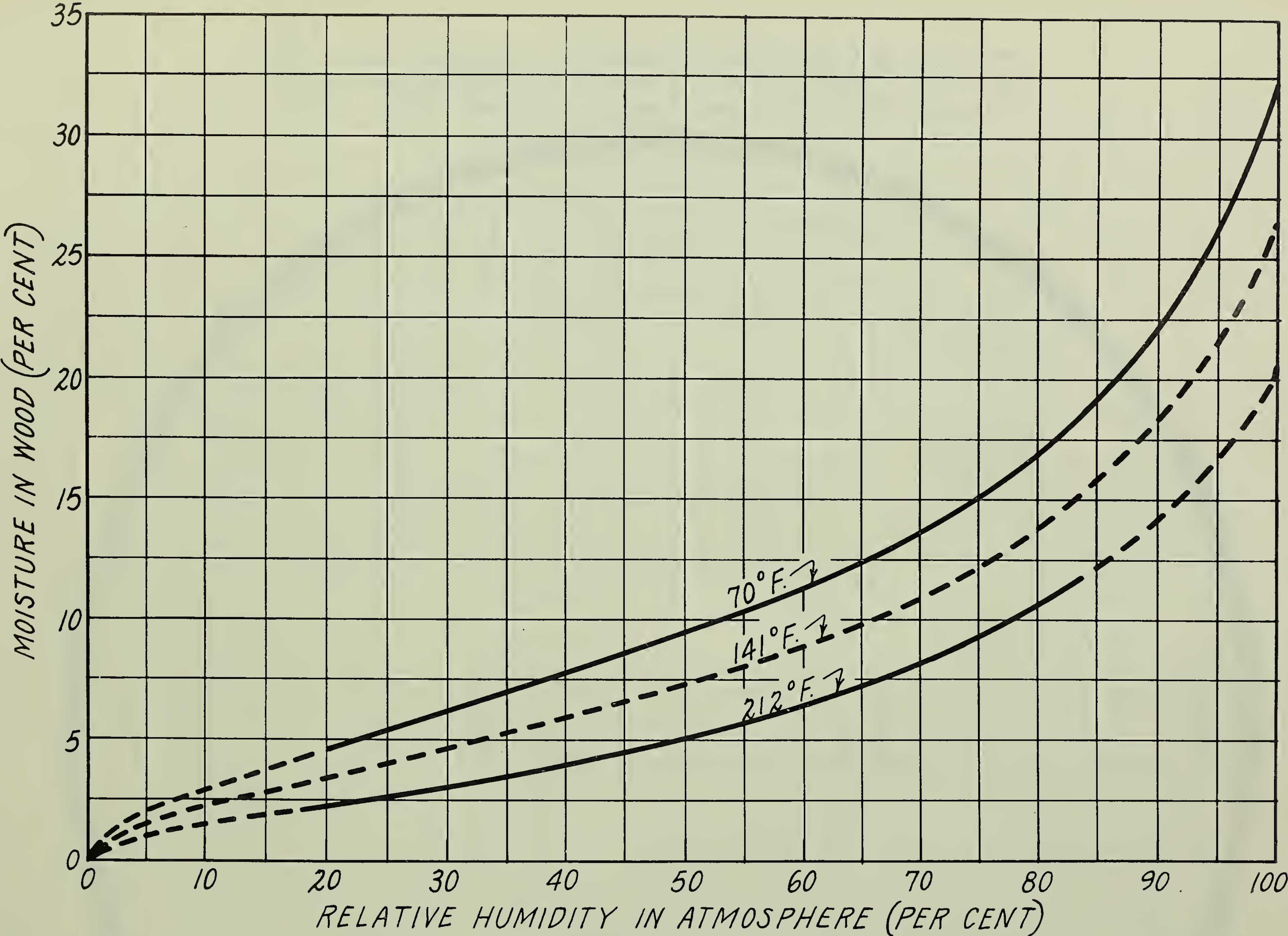

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Fig. 2. Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere, at three temperatures.

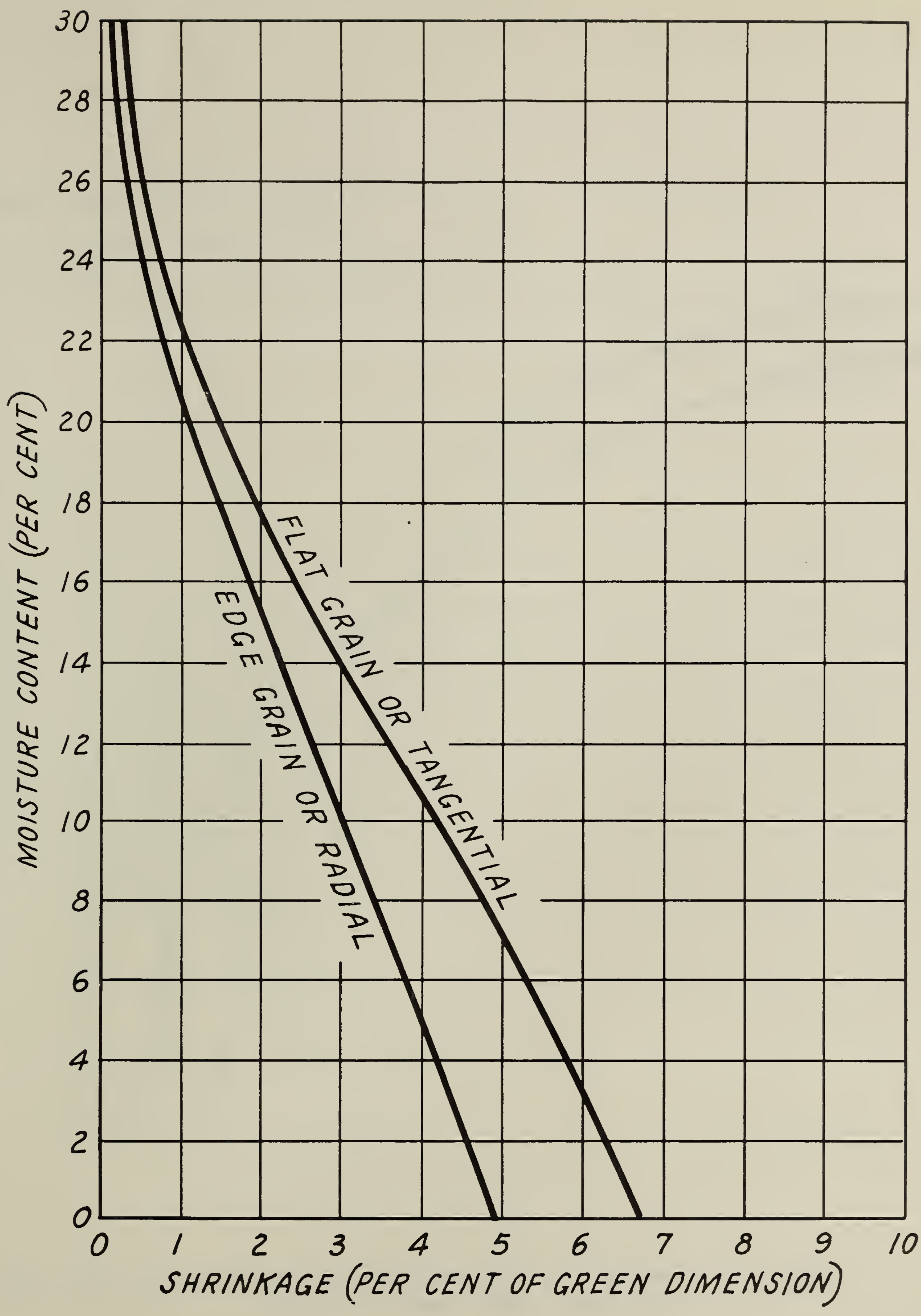

Figure 3.--Typical moisture-shrinkage curves. These curves are for Douglas-fir and southern yellow pine and may be used for estimating the amount of change in dimension that will take place with change in the moisture content of the wood.

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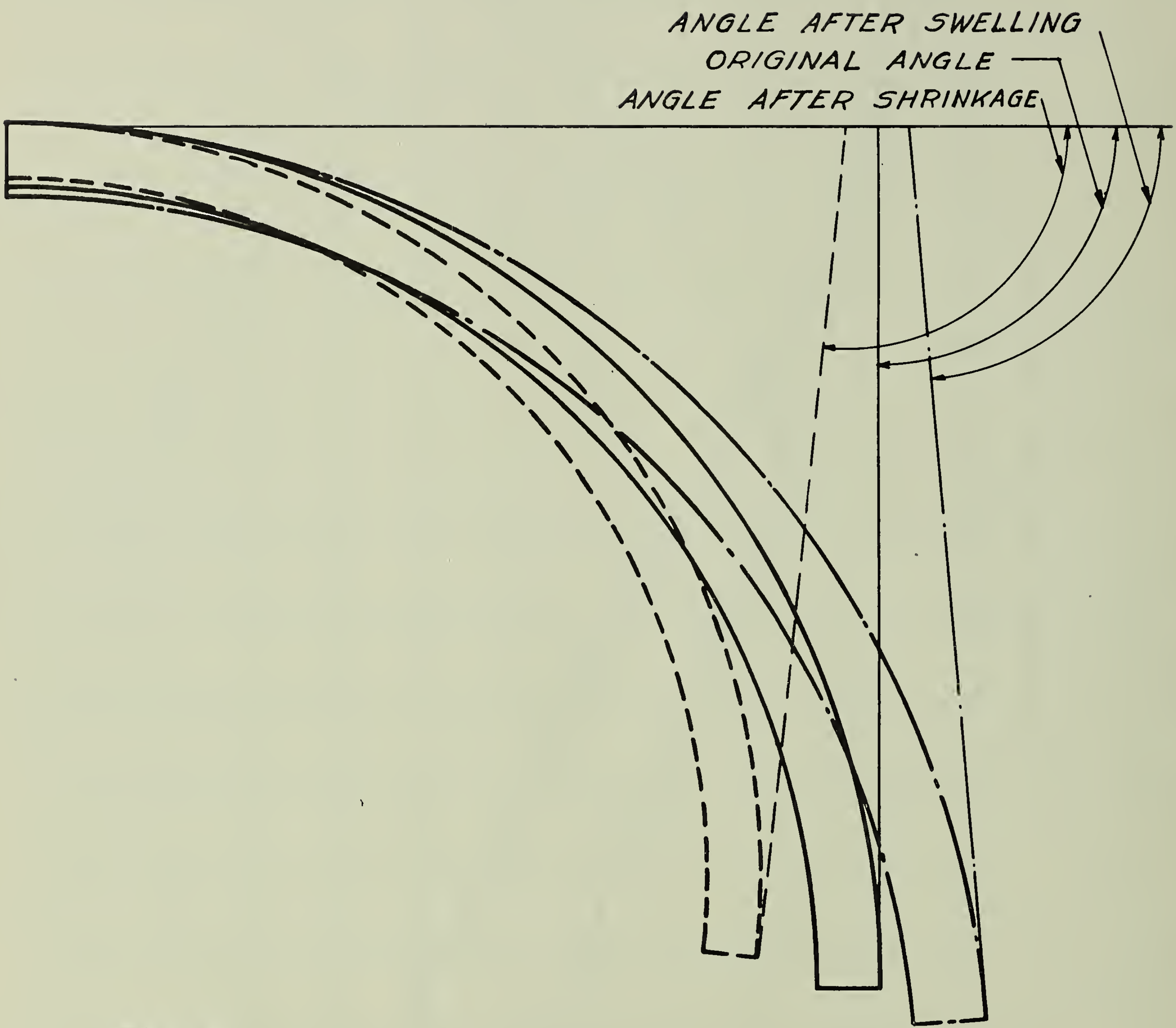

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Figure 4.--Changes in curved wood member caused by shrinkage and swelling. (Not drawn to scale.)